Appendix A

Charcoal Canister Analyses Support Documents

ACCURACY APPRAISAL TABLE
NOVEMBER 2012 SAMPLING

ENERGY FUELS RESOURCES
WHITE MESA MILL, BLANDING, UTAH
2012 NESHAPs RADON FLUX MEASUREMENTS
SAMPLING DATES: 11/19/12-11/20/12

SYSTEM I.D.	DATE	Bkg Counts (1 min. each) #1	#2	#3	Source Counts (1 min. each) #1	#2	#3	AVG NET cpm	YIELD cpm/pCi	FOUND pCi	SOURCE ID	KNOWN pCi	% BIAS
M-01/D-21	11/21/2012	153	147	154	10215	10296	10253	10103	0.1713	58980	GS-04	59300	-0.5%
M-01/D-21	11/21/2012	155	152	146	10333	10279	10301	10153	0.1713	59272	GS-04	59300	0.0%
M-01/D-21	11/22/2012	155	126	150	10132	10157	10101	9986	0.1713	58297	GS-04	59300	-1.7%
M-01/D-21	11/22/2012	151	139	137	10303	10114	10132	10041	0.1713	58615	GS-04	59300	-1.2%
M-01/D-21	11/21/2012	153	147	154	10287	10274	10238	10115	0.1713	59048	GS-05	59300	-0.4%
M-01/D-21	11/21/2012	155	152	146	10347	10270	10318	10161	0.1713	59315	GS-05	59300	0.0%
M-01/D-21	11/22/2012	155	126	150	10215	10066	10069	9973	0.1713	58219	GS-05	59300	-1.8%
M-01/D-21	11/22/2012	151	139	137	10313	10331	10141	10119	0.1713	59074	GS-05	59300	-0.4%
M-02/D-20	11/21/2012	126	143	142	10307	10313	10268	10159	0.1718	59133	GS-04	59300	-0.3%
M-02/D-20	11/21/2012	129	144	136	10241	10240	10228	10100	0.1718	58789	GS-04	59300	-0.9%
M-02/D-20	11/22/2012	138	141	145	10572	10433	10489	10357	0.1718	60283	GS-04	59300	1.7%
M-02/D-20	11/22/2012	125	138	129	10553	10561	10495	10406	0.1718	60568	GS-04	59300	2.1%
M-02/D-20	11/21/2012	126	143	142	10096	10040	10071	9932	0.1718	57811	GS-05	59300	-2.5%
M-02/D-20	11/21/2012	129	144	136	10197	10058	10162	10003	0.1718	58223	GS-05	59300	-1.8%
M-02/D-20	11/22/2012	138	141	145	10594	10187	10453	10270	0.1718	59779	GS-05	59300	0.8%
M-02/D-20	11/22/2012	125	138	129	10483	10599	10624	10438	0.1718	60757	GS-05	59300	2.5%
AVERAGE PERCENT BIAS FOR ALL ANALYTICAL SESSIONS:													-0.3%

CHARCOAL CANISTER ANALYSIS SYSTEM

SITE LOCATION: White Mesa Mill, Blanding, UT

CLIENT: Energy Fuels Resources

Calibration Check Log

System ID: M-01/D-21 Calibration Date: 6/09/12 Due Date: 6/09/13

Scaler S/N: 51572 High Voltage: 1125 Window: 4.42 Thrshld: 2.20

Detector S/N: 041533 Source ID/SN: Ra^{226}/GS-04 Source Activity: 59.3KpCi

Blank Canister Bkgd. Range, cpm: 2 σ = 119 to 158 3 σ = 110 to 167

Gross Source Range, cpm: 2 σ = 10095 to 10481 3 σ = 9998 to 10578

Technician: DLCoop

All counts times are one minute.

	Date	By	Background Counts (1 min. each)				Source Counts (1 min. each)				ok?
			#1	#2	#3	Avg.	#1	#2	#3	Average	Y/N
Pre	11/21/12	DLCoop	153	147	154	151	10215	10296	10253	10255	Y
Post	11/21/12	DLCoop	155	152	146	151	10333	10279	10301	10304	Y
Pre	11/22/12	DLCoop	155	126	150	144	10132	10157	10101	10130	Y
Post	11/22/12	DLCoop	151	139	137	142	10303	10114	10132	10183	Y

Y/N: Y = average background and source cpm falls within the control limits.
N = average background and source cpm does not fall within the control limits.

The acceptable ranges were determined from prior background and source check data.

CHARCOAL CANISTER ANALYSIS SYSTEM

SITE LOCATION: White Mesa Mill, Blanding, UT

CLIENT: Energy Fuels Resources

Calibration Check Log

System ID: M-01/D-21 Calibration Date: 6/09/12 Due Date: 6/09/13

Scaler S/N: 51572 High Voltage: 1125 Window: 4.42 Thrshld: 2.20

Detector S/N: 041533 Source ID/SN: Ra226/GS-05 Source Activity: 59.3KpCi

Blank Canister Bkgd. Range, cpm: 2 σ = 119 to 158 3 σ = 110 to 167

Gross Source Range, cpm: 2 σ = 10059 to 10423 3 σ = 9968 to 10514

Technician: DL Coop

All counts times are one minute.

	Date	By	Background Counts (1 min. each)				Source Counts (1 min. each)				ok?
			#1	#2	#3	Avg.	#1	#2	#3	Average	Y/N
Pre	11/21/12	DL Coop	153	147	154	151	10287	10274	10238	10266	Y
Post	11/21/12	DL Coop	155	152	146	151	10347	10270	10318	10312	Y
Pre	11/22/12	DL Coop	155	126	150	144	10215	10066	10069	10117	Y
Post	11/22/12	DL Coop	151	139	137	142	10313	10331	10141	10262	Y

Y/N: Y = average background and source cpm falls within the control limits.
N = average background and source cpm does not fall within the control limits.

The acceptable ranges were determined from prior background and source check data.

CHARCOAL CANISTER ANALYSIS SYSTEM

SITE LOCATION: White Mesa Mill, Blanding, UT

CLIENT: Energy Fuels Resources

Calibration Check Log

System ID: M-02/D-20 Calibration Date: 6/09/12 Due Date: 6/09/13

Scaler S/N: 51563 High Voltage: 825 Window: 4.42 Thrshld: 2.20

Detector S/N: 041532 Source ID/SN: Ra^{226}/GS-04 Source Activity: 59.3 KpCi

Blank Canister Bkgd. Range, cpm: 2σ = 124 to 152 3σ = 117 to 159

Gross Source Range, cpm: 2σ = 10211 to 10605 3σ = 10113 to 10704

Technician: DL Cogan

All counts times are one minute.

	Date	By	Background Counts (1 min. each)				Source Counts (1 min. each)				ok?
			#1	#2	#3	Avg.	#1	#2	#3	Average	Y/N
Pre	11/21/12	DLCogan	126	143	142	137	10307	10313	10268	10296	Y
Post	11/21/12	DLCogan	129	144	136	136	10241	10240	10228	10236	Y
Pre	11/22/12	DLCogan	138	141	145	141	10572	10433	10489	10498	Y
Post	11/22/12	DLCogan	125	138	129	131	10553	10561	10495	10536	Y

Y/N: Y = average background and source cpm falls within the control limits.
N = average background and source cpm does not fall within the control limits.

The acceptable ranges were determined from prior background and source check data.

CHARCOAL CANISTER ANALYSIS SYSTEM

SITE LOCATION: White Mesa Mill, Blanding, UT

CLIENT: Energy Fuels Resources

Calibration Check Log

System ID: M-02/ D-20 Calibration Date: 6/09/12 Due Date: 6/09/13

Scaler S/N: 51563 High Voltage: 825 Window: 4.42 Thrshld: 2.20

Detector S/N: 041532 Source ID/SN: Ra226/GS-05 Source Activity: 59.3KpCi

Blank Canister Bkgd. Range, cpm: 2 σ = 124 to 152 3 σ = 117 to 159

Gross Source Range, cpm: 2 σ = 10031 to 10667 3 σ = 9872 to 10826

Technician: DL Cooper

All counts times are one minute.

	Date	By	Background Counts (1 min. each)				Source Counts (1 min. each)				ok?
			#1	#2	#3	Avg.	#1	#2	#3	Average	Y/N
Pre	11/21/12	DLCoop	126	143	142	137	10096	10040	10071	10069	Y
Post	11/21/12	DLCoop	129	144	136	136	10197	10058	10162	10139	Y
Pre	11/22/12	DLCoop	138	141	145	141	10594	10187	10453	10411	Y
Post	11/22/12	DLCoop	125	138	129	131	10483	10599	10624	10569	Y

Y/N: Y = average background and source cpm falls within the control limits.
N = average background and source cpm does not fall within the control limits.

The acceptable ranges were determined from prior background and source check data.

Appendix B

Recount Data Analyses

CLIENT: DENISON MINES PROJECT: RADON FLUX MEASUREMENTS, WHITE MESA MILL PROJECT NO.: 12004.00

PILE: 2 BATCH: I SURFACE: SOIL AIR TEMP MIN: 31°F WEATHER: NO RAIN
AREA: COVER DEPLOYED: 11 19 12 RETRIEVED: 11 20 12 CHARCOAL BKG: 148 cpm Wt. Out: 180.0 g.
FIELD TECHNICIANS: CS,MC,DLC COUNTED BY: DLC DATA ENTRY BY: MC TARE WEIGHT: 29.2 g.
COUNTING SYSTEM I.D.: M01/D21, M02/D20 CAL. DUE: 6/09/13

RECOUNT CANISTER ANALYSIS:

GRID	SAMPLE			RETRIV		ANALYSIS			MID-TIME		CNT	GROSS	GROSS	RADON	±	LLD	PRECISION
LOCATION	I. D.	HR	MIN	HR	MIN	MO	DA	YR	HR	MIN	(MIN)	COUNTS	WT IN	pCi/m^2s	pCi/m^2s	pCi/m^2s	% RPD
I10	I10	8	16	8	30	11	21	12	10	4	1	5337	216.3	8.7	0.9	0.03	
RECOUNT	I10	8	16	8	30	11	22	12	8	55	1	4509	216.3	8.7	0.9	0.04	0.0%
I20	I20	8	28	8	36	11	21	12	10	13	1	12397	211.6	20.6	2.1	0.03	
RECOUNT	I20	8	28	8	36	11	22	12	8	55	1	10679	211.6	21.1	2.1	0.04	2.4%
I30	I30	8	52	8	51	11	21	12	10	21	1	36295	217.1	61.2	6.1	0.03	
RECOUNT	I30	8	52	8	51	11	22	12	8	57	1	30964	217.1	61.9	6.2	0.04	1.1%
I40	I40	8	38	8	44	11	21	12	10	28	1	36981	213.4	62.2	6.2	0.03	
RECOUNT	I40	8	38	8	44	11	22	12	8	57	1	32570	213.4	64.9	6.5	0.04	4.2%
I50	I50	9	17	9	4	11	21	12	10	36	1	7340	210.2	12.3	1.2	0.03	
RECOUNT	I50	9	17	9	4	11	22	12	8	58	1	6230	210.2	12.3	1.2	0.04	0.0%
I60	I60	9	6	8	57	11	21	12	10	46	1	1664	214.5	2.6	0.3	0.03	
RECOUNT	I60	9	6	8	57	11	22	12	8	58	1	1467	214.5	2.7	0.3	0.04	3.8%
I70	I70	9	24	9	12	11	21	12	10	56	1	16423	215.6	27.8	2.8	0.03	
RECOUNT	I70	9	24	9	12	11	22	12	8	59	1	14526	215.6	29.0	2.9	0.04	4.2%
I80	I80	8	57	8	48	11	21	12	11	6	2	1462	212.8	1.0	0.1	0.03	
RECOUNT	I80	8	57	8	48	11	22	12	9	0	2	1350	212.8	1.1	0.1	0.04	9.5%
I90	I90	8	14	8	29	11	21	12	11	16	2	1219	218.1	0.78	0.1	0.03	
RECOUNT	I90	8	14	8	29	11	22	12	9	2	2	1133	218.1	0.83	0.1	0.04	6.2%
I100	I100	8	8	8	26	11	21	12	11	27	2	1906	217.1	1.4	0.1	0.03	
RECOUNT	I100	8	8	8	26	11	22	12	9	3	2	1823	217.1	1.5	0.2	0.04	6.9%
																AVERAGE PERCENT PRECISION FOR THE CELL 2 COVER REGION:	3.8%

Appendix C

Radon Flux Sample Laboratory Data (including Blanks)

CLIENT: DENISON MINES | PROJECT: RADON FLUX MEASUREMENTS, WHITE MESA MILL | PROJECT NO.: 12004.00

PILE: 2 | BATCH: I | SURFACE: SOIL | AIR TEMP MIN: 31°F | WEATHER: NO RAIN

AREA: COVER | DEPLOYED: 11 19 12 | RETRIEVED: 11 20 12 | CHARCOAL BKG: 148 cpm | Wt. Out: 180.0 g.

FIELD TECHNICIANS: CS,MC,DLC | COUNTED BY: DLC | DATA ENTRY BY: MC | TARE WEIGHT: 29.2 g.

COUNTING SYSTEM I.D.: M01/D21, M02/D20 | CAL. DUE: 6/09/13

GRID LOCATION	SAMPLE I. D.	DEPLOY HR	DEPLOY MIN	RETRIV HR	RETRIV MIN	ANALYSIS MO	ANALYSIS DA	ANALYSIS YR	MID-TIME HR	MID-TIME MIN	CNT (MIN)	GROSS COUNTS	GROSS WT IN	RADON pCi/m^2s	± pCi/m^2s	LLD pCi/m^2s	COMMENTS:
I01	I01	8	3	8	24	11	21	12	9	55	1	1921	214.7	3.0	0.3	0.03	
I02	I02	8	4	8	25	11	21	12	9	55	1	15684	217.8	25.9	2.6	0.03	
I03	I03	8	6	8	25	11	21	12	9	56	1	1302	214.0	2.0	0.2	0.03	
I04	I04	8	7	8	26	11	21	12	9	56	1	20166	213.7	33.5	3.3	0.03	
I05	I05	8	9	8	27	11	21	12	9	59	2	1731	213.0	1.2	0.1	0.03	
I06	I06	8	10	8	27	11	21	12	9	58	1	1831	216.6	2.8	0.3	0.03	
I07	I07	8	11	8	28	11	21	12	10	3	1	20931	208.8	35.2	3.5	0.03	
I08	I08	8	13	8	29	11	21	12	10	3	1	2331	215.4	3.7	0.4	0.03	
I09	I09	8	14	8	29	11	21	12	10	4	1	25546	214.6	43.1	4.3	0.03	
I10	I10	8	16	8	30	11	21	12	10	4	1	5337	216.3	8.7	0.9	0.03	
I11	I11	8	17	8	30	11	21	12	10	6	1	19805	216.1	33.4	3.3	0.03	
I12	I12	8	18	8	31	11	21	12	10	6	1	8890	212.6	14.7	1.5	0.03	
I13	I13	8	20	8	32	11	21	12	10	7	1	12516	214.5	21.0	2.1	0.03	
I14	I14	8	21	8	32	11	21	12	10	7	1	7168	211.4	11.8	1.2	0.03	
I15	I15	8	22	8	33	11	21	12									Spilled
I16	I16	8	24	8	34	11	21	12	10	9	1	22628	213.6	37.8	3.8	0.03	
I17	I17	8	25	8	34	11	21	12	10	10	1	21041	214.1	35.6	3.6	0.03	
I18	I18	8	36	8	41	11	21	12	10	11	2	1778	214.0	1.2	0.1	0.03	
I19	I19	8	27	8	35	11	21	12	10	13	1	17157	213.7	29.0	2.9	0.03	
I20	I20	8	28	8	36	11	21	12	10	13	1	12397	211.6	20.6	2.1	0.03	
I21	I21	9	4	8	57	11	21	12	10	14	1	1001	217.2	1.5	0.1	0.03	
I22	I22	9	3	8	56	11	21	12	10	14	1	14881	213.8	25.0	2.5	0.03	
I23	I23	9	2	8	55	11	21	12	10	16	1	1280	215.8	1.9	0.2	0.03	
I24	I24	9	0	8	55	11	21	12	10	16	1	13781	213.4	23.1	2.3	0.03	
I25	I25	8	59	8	54	11	21	12	10	17	1	20068	213.0	34.1	3.4	0.03	
I26	I26	8	57	8	53	11	21	12	10	17	1	19712	213.7	33.1	3.3	0.03	
I27	I27	8	56	8	53	11	21	12	10	19	1	3599	217.2	5.9	0.6	0.03	
I28	I28	8	55	8	52	11	21	12	10	19	1	32130	212.0	54.2	5.4	0.03	
I29	I29	8	53	8	51	11	21	12	10	21	1	20078	216.0	34.1	3.4	0.03	
I30	I30	8	52	8	51	11	21	12	10	21	1	36295	217.1	61.2	6.1	0.03	
I31	I31	8	51	8	50	11	21	12	10	22	1	6438	213.2	10.8	1.1	0.03	
I32	I32	8	49	8	50	11	21	12	10	22	1	45278	215.0	76.3	7.6	0.03	
I33	I33	8	47	8	49	11	21	12	10	24	1	7820	215.1	13.1	1.3	0.03	
I34	I34	8	46	8	48	11	21	12	10	24	1	23551	215.5	39.6	4.0	0.03	

CLIENT: DENISON MINES PROJECT: RADON FLUX MEASUREMENTS, WHITE MESA MILL PROJECT NO.: 12004.00

PILE: 2 BATCH: I SURFACE: SOIL AIR TEMP MIN: 31°F WEATHER: NO RAIN
AREA: COVER DEPLOYED: 11 19 12 RETRIEVED: 11 20 12 CHARCOAL BKG: 148 cpm Wt. Out: 180.0 g.
FIELD TECHNICIANS: CS,MC,DLC COUNTED BY: DLC DATA ENTRY BY: MC TARE WEIGHT: 29.2 g.
COUNTING SYSTEM I.D.: M01/D21, M02/D20 CAL. DUE: 6/09/13

GRID LOCATION	SAMPLE I. D.	DEPLOY HR	DEPLOY MIN	RETRIV HR	RETRIV MIN	ANALYSIS MO	ANALYSIS DA	ANALYSIS YR	MID-TIME HR	MID-TIME MIN	CNT (MIN)	GROSS COUNTS	GROSS WT IN	RADON pCi/m²s	± pCi/m²s	LLD pCi/m²s	COMMENTS:
I35	I35	8	45	8	48	11	21	12	10	25	1	2546	215.8	4.1	0.4	0.03	
I36	I36	8	44	8	47	11	21	12	10	25	1	31117	214.3	52.3	5.2	0.03	
I37	I37	8	42	8	46	11	21	12	10	27	1	20009	211.7	33.9	3.4	0.03	
I38	I38	8	41	8	46	11	21	12	10	27	1	22982	217.4	38.6	3.9	0.03	
I39	I39	8	39	8	45	11	21	12	10	28	1	22891	211.7	38.8	3.9	0.03	
I40	I40	8	38	8	44	11	21	12	10	28	1	36981	213.4	62.2	6.2	0.03	
I41	I41	9	26	9	10	11	21	12	10	30	1	40096	212.2	68.9	6.9	0.03	
I42	I42	9	25	9	9	11	21	12	10	30	1	8823	216.2	14.8	1.5	0.03	
I43	I43	9	24	9	8	11	21	12	10	31	1	8394	212.5	14.2	1.4	0.03	
I44	I44	9	23	9	8	11	21	12	10	31	1	48478	217.5	82.5	8.2	0.03	
I45	I45	9	22	9	7	11	21	12	10	33	1	64747	213.2	111.5	11.1	0.03	
I46	I46	9	21	9	6	11	21	12	10	33	1	3274	216.6	5.3	0.5	0.03	
I47	I47	9	20	9	6	11	21	12	10	34	1	13037	212.9	22.2	2.2	0.03	
I48	I48	9	19	9	5	11	21	12									Spilled
I49	I49	9	18	9	5	11	21	12	10	36	1	13437	213.1	22.9	2.3	0.03	
I50	I50	9	17	9	4	11	21	12	10	36	1	7340	210.2	12.3	1.2	0.03	
I51	I51	9	16	9	3	11	21	12	10	37	1	32849	215.2	56.4	5.6	0.03	
I52	I52	9	15	9	3	11	21	12	10	37	1	11086	213.4	18.7	1.9	0.03	
I53	I53	9	14	9	2	11	21	12	10	39	1	86623	214.0	149.2	14.9	0.03	
I54	I54	9	13	9	1	11	21	12	10	39	1	26161	214.2	44.4	4.4	0.03	
I55	I55	9	12	9	1	11	21	12	10	40	1	3321	212.4	5.5	0.5	0.03	
I56	I56	9	11	9	0	11	21	12	10	40	1	125022	212.6	213.0	21.3	0.03	
I57	I57	9	10	8	59	11	21	12	10	42	1	86635	213.4	149.2	14.9	0.03	
I58	I58	9	9	8	59	11	21	12	10	43	2	1792	213.9	1.3	0.1	0.03	
I59	I59	9	7	8	58	11	21	12	10	47	2	1727	214.7	1.2	0.1	0.03	
I60	I60	9	6	8	57	11	21	12	10	46	1	1664	214.5	2.6	0.3	0.03	
I61	I61	9	27	9	10	11	21	12	10	50	1	4918	212.6	8.3	0.8	0.03	
I62	I62	9	28	9	11	11	21	12	10	50	1	3779	215.0	6.2	0.6	0.03	
I63	I63	9	29	9	12	11	21	12	10	51	1	2616	212.4	4.3	0.4	0.03	
I64	I64	9	30	9	12	11	21	12	10	51	1	45122	211.6	77.0	7.7	0.03	
I65	I65	9	31	9	13	11	21	12	10	53	1	16436	212.6	28.2	2.8	0.03	
I66	I66	9	32	9	14	11	21	12	10	53	1	17784	213.7	30.2	3.0	0.03	
I67	I67	9	32	9	14	11	21	12	10	54	1	2891	214.5	4.8	0.5	0.03	
I68	I68	9	30	9	13	11	21	12	10	54	1	4525	213.7	7.5	0.7	0.03	

CLIENT: DENISON MINES PROJECT: RADON FLUX MEASUREMENTS, WHITE MESA MILL PROJECT NO.: 12004.00

PILE: 2 BATCH: I SURFACE: SOIL AIR TEMP MIN: 31°F WEATHER: NO RAIN
AREA: COVER DEPLOYED: 11 19 12 RETRIEVED: 11 20 12 CHARCOAL BKG: 148 cpm Wt. Out: 180.0 g.
FIELD TECHNICIANS: CS,MC,DLC COUNTED BY: DLC DATA ENTRY BY: MC TARE WEIGHT: 29.2 g.
COUNTING SYSTEM I.D.: M01/D21, M02/D20 CAL. DUE: 6/09/13

GRID LOCATION	SAMPLE I. D.	DEPLOY HR	DEPLOY MIN	RETRIV HR	RETRIV MIN	ANALYSIS MO	ANALYSIS DA	ANALYSIS YR	MID-TIME HR	MID-TIME MIN	CNT (MIN)	GROSS COUNTS	GROSS WT IN	RADON pCi/m^2s	± pCi/m^2s	LLD pCi/m^2s	COMMENTS:
I69	I69	9	27	9	13	11	21	12	10	56	1	8036	219.9	13.6	1.4	0.03	
I70	I70	9	24	9	12	11	21	12	10	56	1	16423	215.6	27.8	2.8	0.03	
I71	I71	9	22	9	11	11	21	12	10	57	1	19671	218.7	33.7	3.4	0.03	
I72	I72	9	19	9	10	11	21	12	10	57	1	8845	215.5	14.8	1.5	0.03	
I73	I73	9	16	9	9	11	21	12	10	59	1	13675	215.6	23.3	2.3	0.03	
I74	I74	9	13	9	9	11	21	12	10	59	1	1531	218.2	2.4	0.2	0.03	
I75	I75	9	11	9	8	11	21	12	11	0	1	1376	215.7	2.1	0.2	0.03	
I76	I76	9	8	9	7	11	21	12	11	0	1	5333	218.3	8.8	0.9	0.03	
I77	I77	9	5	8	45	11	21	12	11	2	1	34662	213.6	60.1	6.0	0.03	
I78	I78	9	3	8	46	11	21	12	11	3	2	1363	214.9	0.9	0.1	0.03	
I79	I79	9	0	8	47	11	21	12	11	5	1	4326	216.3	7.2	0.7	0.03	
I80	I80	8	57	8	48	11	21	12	11	6	2	1462	212.8	1.0	0.1	0.03	
I81	I81	8	54	8	49	11	21	12	11	9	1	5464	215.7	9.2	0.9	0.03	
I82	I82	8	52	8	50	11	21	12	11	9	1	17101	215.9	28.9	2.9	0.03	
I83	I83	8	49	8	52	11	21	12	11	10	1	17872	213.8	30.4	3.0	0.03	
I84	I84	8	46	8	54	11	21	12	11	10	1	1974	215.9	3.1	0.3	0.03	
I85	I85	8	43	8	56	11	21	12	11	12	1	4035	216.0	6.6	0.7	0.03	
I86	I86	8	41	8	57	11	21	12	11	12	1	5044	213.1	8.2	0.8	0.03	
I87	I87	8	38	8	59	11	21	12	11	13	1	2715	213.1	4.4	0.4	0.03	
I88	I88	8	35	9	0	11	21	12	11	13	1	5165	216.5	8.4	0.8	0.03	
I89	I89	8	11	8	28	11	21	12	11	15	1	4217	216.6	7.0	0.7	0.03	
I90	I90	8	14	8	29	11	21	12	11	16	2	1219	218.1	0.8	0.1	0.03	
I91	I91	8	16	8	30	11	21	12	11	19	2	1477	216.9	1.0	0.1	0.03	
I92	I92	8	19	8	32	11	21	12	11	19	1	2254	218.4	3.6	0.4	0.03	
I93	I93	8	22	8	33	11	21	12	11	22	1	6130	218.7	10.3	1.0	0.03	
I94	I94	8	25	8	34	11	21	12	11	22	1	1717	214.2	2.7	0.3	0.03	
I95	I95	8	27	8	36	11	21	12	11	23	1	2428	217.7	3.9	0.4	0.03	
I96	I96	8	30	8	37	11	21	12	11	23	1	4077	214.0	6.7	0.7	0.03	
I97	I97	8	33	8	38	11	21	12	11	25	1	21390	214.6	36.6	3.7	0.03	
I98	I98	8	3	8	24	11	21	12	11	25	1	7843	217.0	13.0	1.3	0.03	
I99	I99	8	6	8	25	11	21	12	11	26	1	5755	215.1	9.6	1.0	0.03	
I100	I100	8	8	8	26	11	21	12	11	27	2	1906	217.1	1.4	0.1	0.03	

AVERAGE RADON FLUX RATE FOR THE CELL 2 COVER REGION: 26.1 pCi/m^2s

CLIENT: DENISON MINES PROJECT: RADON FLUX MEASUREMENTS, WHITE MESA MILL PROJECT NO.: 12004.00

PILE: 2 BATCH: I SURFACE: SOIL AIR TEMP MIN: 31°F WEATHER: NO RAIN
AREA: COVER DEPLOYED: 11 19 12 RETRIEVED: 11 20 12 CHARCOAL BKG: 148 cpm Wt. Out: 180.0 g.
FIELD TECHNICIANS: CS,MC,DLC COUNTED BY: DLC DATA ENTRY BY: MC TARE WEIGHT: 29.2 g.
COUNTING SYSTEM I.D.: M01/D21, M02/D20 CAL. DUE: 6/09/13

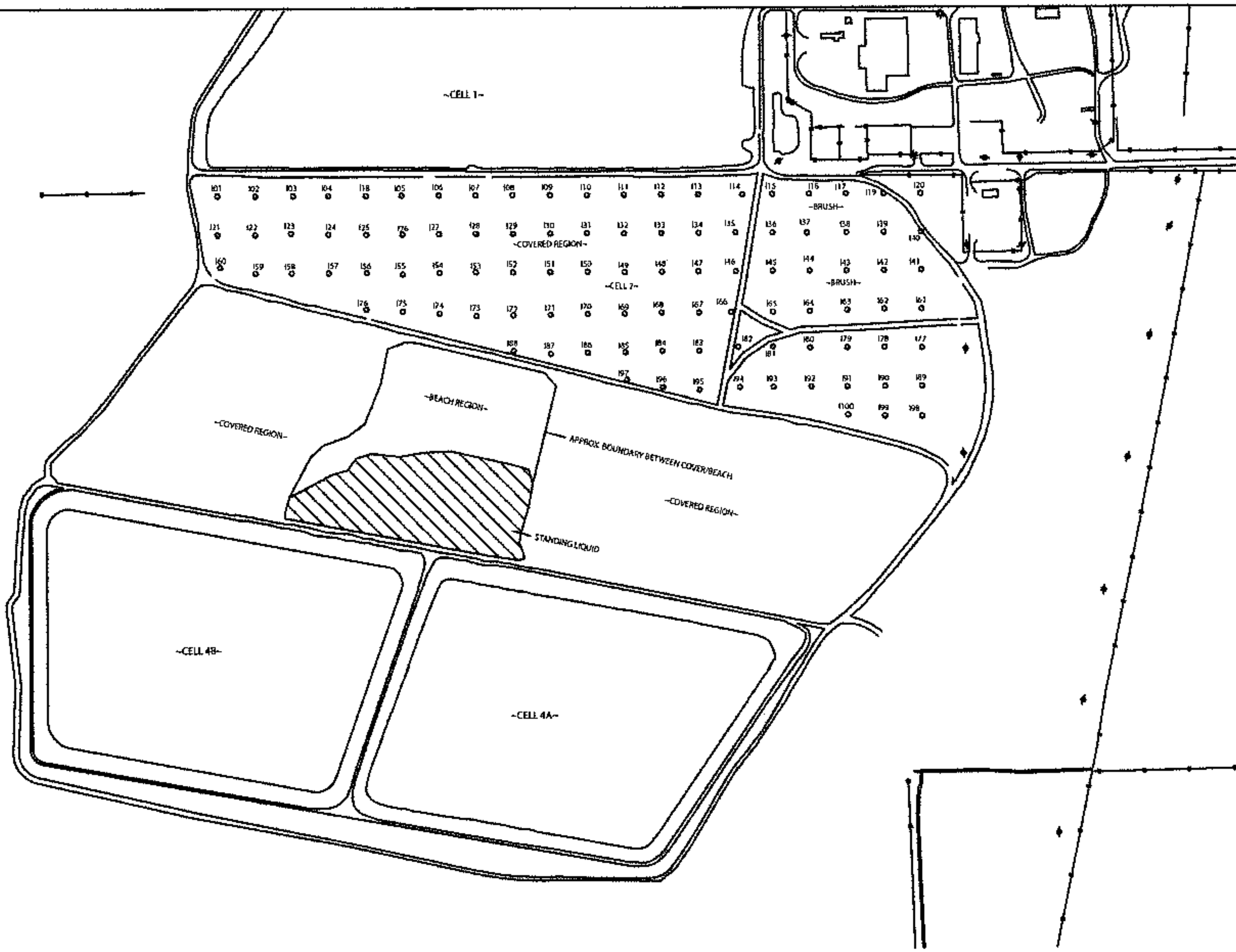
BLANK CANISTER ANALYSIS:

GRID LOCATION	SAMPLE I. D.	HR	MIN	RETRIV HR	MIN	ANALYSIS MO	DA	YR	MID-TIME HR	MIN	CNT (MIN)	GROSS COUNTS	GROSS WT IN	RADON pCi/m²s	± pCi/m²s	LLD pCi/m²s	COMMENTS:
I BLANK 1	I BLANK 1	8	0	8	25	11	21	12	9	5	10	1680	202.0	0.03	0.02	0.03	CONTROL
I BLANK 2	I BLANK 2	8	0	8	25	11	21	12	9	5	10	1596	208.6	0.02	0.02	0.03	CONTROL
I BLANK 3	I BLANK 3	8	0	8	25	11	21	12	9	18	10	1666	209.3	0.03	0.02	0.03	CONTROL
I BLANK 4	I BLANK 4	8	0	8	25	11	21	12	9	18	10	1638	210.5	0.03	0.02	0.03	CONTROL
I BLANK 5	I BLANK 5	8	0	8	25	11	21	12	9	30	10	1705	207.7	0.04	0.02	0.03	CONTROL

AVERAGE BLANK CANISTER ANALYSIS FOR THE CELL 2 COVER REGION: 0.03 pCi/m²s

Appendix D

Sample Locations Map (Figure 2)



WHITE MESA MILL

BLANDING, UTAH

NESHAPS 2012

NOVEMBER 2012 SAMPLING

PREPARED FOR
ENERGY FUELS RESOURCES

LEGEND

101 - SAMPLE LOCATION ON COVERED AREAS

FIGURE 2

N

SCALE IN FEET
200 100 0 200 400

TELLCO
ENVIRONMENTAL, LLC

ATTACHMENT 2

SENES Consultants Limited Technical Memorandum

WHITE MESA MILL CELL 2 RADON FLUX

Prepared for:

Energy Fuels Resources (USA) Inc.
225 Union Blvd., Suite 600,
Lakewood, CO, US, 80228

Prepared by:

SENES Consultants Limited
121 Granton Drive, Unit 12
Richmond Hill, Ontario
L4B 3N4

March 2013

EXECUTIVE SUMMARY

Energy Fuels Resources (USA) Inc. (EFRI) is currently preparing one of their uranium tailing cells (Cell 2) at their White Mesa Uranium Mill, located in San Juan County Utah, for final reclamation. One of the regulatory requirements for site licensing is meeting the long-term radon emanation standard for uranium mill tailings, and therefore, EFRI must install an engineered cover designed to limit the flux of radon to the atmosphere to the applicable limit of 20 pCi m^{-2} s^{-1}. During operations, prior to installation of the final engineered cover, the tailings cell must also maintain radon emissions from the cell within this 20 pCi m^{-2} s^{-1} standard.

In order to place the final cover, the tailings need to be first dewatered and stabilized. Since the ability of radon to diffuse through air is several orders of magnitude larger than through water, the radon flux from the surface of tailings in the process of reclamation is expected to increase as the tailings are progressively dewatered.

The present report looks at the potential effects of dewatering on the radon flux from Cell 2. The radon model used in this report was based on the detailed methodology recommended by the U.S. NRC Regulatory Guide 3.46 (1989), which uses a one-dimensional steady-state gas diffusion model. The parameter values were based on values used in MWH (2011) updated by insight gained from recent measurements of thicknesses of cover, depth to water table in the tailings and radon fluxes in Cell 2.

The analyses provided in this report confirm that, as expected on the basis of diffusion principles, the radon flux from the surface of the Cell 2 tailings is expected to increase as dewatering progresses.

The dewatering operation is expected to take several years to complete, and, if addition of temporary cover of random fill is not technically or financially feasible, exceeding the radon flux standard will be an unavoidable but temporary consequence of the dewatering actions required to reclaim Cell 2. This elevated radon flux will persist through reclamation but would be reduced to below the regulatory limit once the final cover is in place.

In order to explore potential interim actions that could be taken to maintain radon flux within the 20 pCi m^{-2} s^{-1} standard, we have also evaluated the extent to which radon emanations from the cell can be reduced by increasing the thickness of the current interim cover on Cell 2. Based on our analysis, we have concluded that (a) the addition of approximately 0.5 feet of random fill cover (at between 80 and 95% compaction) to the current interim cover would be expected to reduce the average radon flux from its current rate of approximately 26 pCi m^{-2} s^{-1} to less than 20 pCi m^{-2} s^{-1}, (b) the addition of approximately 1.0 feet of random fill cover (at 80 to 95% compaction) to the current interim cover would be expected to reduce the average flux of approximately 26 pCi m^{-2} s^{-1}, plus the increased radon resulting from further dewatering over approximately the next year, to less than 20 pCi m^{-2} s^{-1}, and (c) the addition of approximately 2.0 feet of random fill cover (at 80 to 95% compaction) to the current interim cover would reasonably be expected to be sufficient to reduce surface radon flux to below 20 pCi m^{-2} s^{-1}, regardless of the depth of dewatered tails.

TABLE OF CONTENTS

Page No.

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

SENES Consultants Limited (SENES) was retained by Energy Fuels Resources (USA) Inc. (EFRI) to conduct an assessment of radon flux arising from the reclamation of one of their tailing cells (Cell 2) at the White Mesa Uranium Mill in San Juan County Utah (the "Mill").

Between 1980 and 2000, about 3,911,000 tons of ore with an average ore grade of about 0.350% U_3O_8 were processed in the mill, as a result of which some 2,337,000 tons of tailings were placed in Cell 2 at the Mill. Soil stockpiled at the site (loam to sandy clay - referred to hereafter as "random fill") was used to cover the tailings until 2007, when Cell 2 was completely covered by about 4.5 ft. of random fill. As part of developing the final reclamation actions required to achieve the radon flux standard of 20 pCi m^{-2} s^{-1}, a final engineered cover was designed by TITAN Environmental (1996), and an updated design has recently been proposed by MWH Americas Inc. (2011), which is currently under review by the Utah Department of Environmental Quality, Division of Radiation Control ("DRC").

To place the final cover, the tailings first need to be dewatered and stabilized. This process is required under Part I.D.3(b) of the Mill's State of Utah Groundwater Discharge Permit, and is also part of the reclamation actions which are currently underway and will require a number of years to complete. Since the ability of radon to diffuse through water is several orders of magnitude lower than through air, the radon flux from the surface of tailings in the process of reclamation should be expected to increase as the tailings are progressively dewatered.

Release of radon from uranium tailings is regulated by the U.S. EPA's Code of Federal Regulations at 40 CFR Part 61.250, for operating mill tailings and at 40 CFR Part 194 (EPA 1986) for reclaimed mill tailings. For operating mill tailings, 40 CFR 61.252 provides that '*Radon-222 emissions to the ambient air from an existing uranium mill tailings pile shall not exceed 20 pCi/m²/sec of radon-222.*' For reclaimed tailings, 40 CFR Part 194 requires that '... *uranium tailings cover be designed to produce reasonable assurance that the radon-222 release rate would not exceed 20 pCi/m²/sec for a period of 1,000 years to the extent reasonably achievable and in any case for at least 200 years when averaged over the disposal area over at least a one year period*'. This standard has also been adopted by the State of Utah, which licenses the Mill, as the long-term emanation standard for uranium mill tailings (Utah Administrative Code Rule 313-24).

For the short term drying conditions (during which a portion of the tailings will lose saturation and the formerly water-filled tailings pore space will become air-filled) an increase in radon flux should be expected, which could lead to a radon flux in excess of the 20 pCi m^{-2} s^{-1} standard set out in 40 CFR 61.252. There are provisions for new tailings facilities (i.e. those constructed after December 15, 1989) which are subject to phased disposal (U.S. EPA 1998), and which are not subject to the 20 pCi m^{-2} s^{-1} standard set out in 40 CFR 61.252 during operations. The increase in radon flux due to dewatering does not pose a problem for such cells. However, the regulations do not address how existing tailings facilities are expected to manage increases in radon flux during the dewatering process prior to installation of the final reclamation cover.

The present report assesses the potential effects of dewatering on the radon flux from Cell 2 during the dewatering process. This report also describes the data and methods used in the assessment. In addition, we provide illustrative calculations of the thickness of a temporary cover needed to achieve the radon flux standard of 20 pCi m^{-2} s^{-1}, during the dewatering process prior to installation of the final reclamation cover.

2.0 BACKGROUND TO TRANSPORT OF RADON THROUGH SOIL

2.1 RADON PRODUCTION

Radon is produced through the radioactive decay of radium-226, and has a half-life of 3.82 days. Radium-226 is a long-lived decay product of the uranium-238 series present in the tailings created through the milling of uranium ore. Radon-222 is the only member of the decay chain which is in a gaseous form. As a (noble) gas, radon-222 can be released to the atmosphere if it emanates from a mineral matrix that contains radium-226. The radon production rate (q) in a porous radium-bearing material can be expressed as:

$$q = [Ra] \times \rho \times \frac{E}{P} \times \lambda = \frac{\beta}{P}$$

where, [Ra] is radium-226 concentration, ρ is bulk density, E is emanation coefficient, P is porosity and λ is radon decay constant. β is defined as the emanation power.

2.2 TRANSPORT THROUGH COVER

When tailings are covered by an inert material, the diffusive radon flux (J) at the surface of the cover can be expressed approximately as:

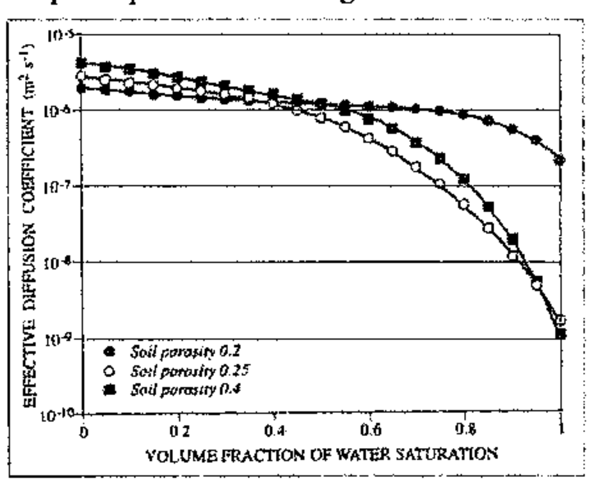
$$J = J_0 e^{\frac{-Z}{L}}$$

where, J_0 is the radon flux from the uncovered tailings, Z is the cover thickness and L is the diffusion length (or the distance to which concentration decreases by a factor of e), defined as follows:

$$L = \sqrt{\frac{D}{\lambda P}}$$

where, D is the bulk diffusion coefficient, and D/P is the effective diffusion coefficient. Experimental effective diffusion coefficients provided by UNSCEAR (2000) are shown in Figure 2-1. The effect of increased water content in pore spaces in reducing diffusion is evident.

FIGURE 2-1 EXPERIMENTAL DIFFUSION COEFFICIENTS (UNSCEAR 2000)



The U.S. EPA (1982, 1986) also provides a (simplified) method for modeling of radon transmission through soil/earth covers. This method uses similar concepts of radon attenuation as outlined above; however, some of the terminology varies slightly. In particular, the EPA refers to a half-value layer (HVL), which is defined as the thickness of material that reduces radon emissions to one-half of its initial value (as distinct from 1/e). The HVLs depend on cover composition and moisture content among other factors that affect the ability of radon to diffuse through the cover. To a reasonable approximation, radon transmission (T) through soil/earth covers of thickness (t) may be approximated as follows:

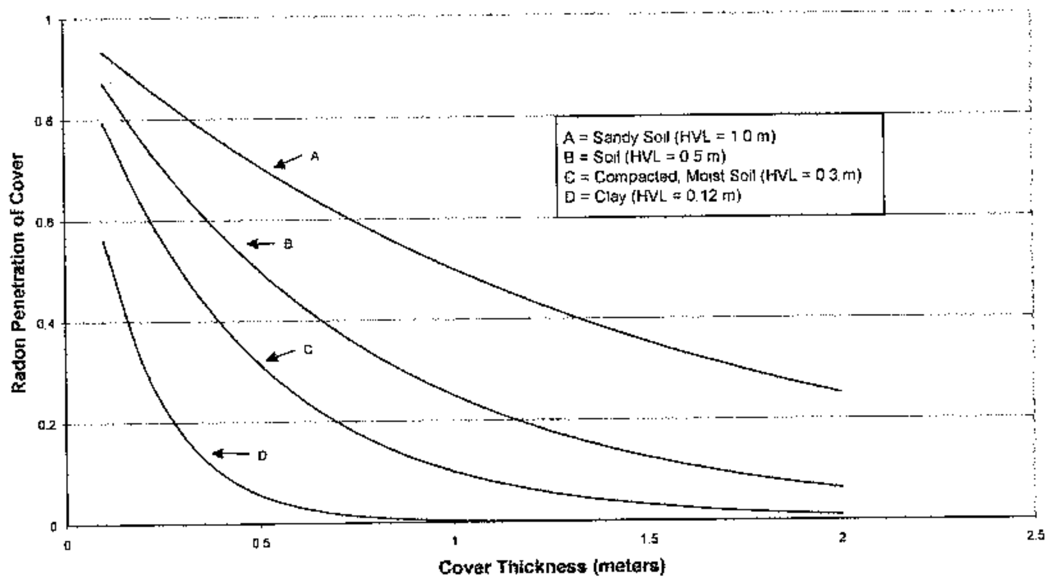
$$T = e^{-t/L}$$

where, L is the cover thickness through which radon is attenuated by a factor of 1/e. The HVL is given by ln(2) *L = 0.693*L. Repeated application of this formula can be used to approximate the effect of multiple covers. HVLs for various covers, and corresponding radon attenuation coefficients and radon transmission factors developed by the EPA are shown in Table 2-1 and illustrated in Figure 2-2.

TABLE 2-1 RADON ATTENUATION OF VARIOUS COVERS (U.S. EPA 1986)

Cover	Moisture (%)	HVL (meters (m))	Attenuation coefficient (1/m)
Sandy soil	3.4	1	0.7
Soil	7.5	0.75	0.9
Soil	12.6	0.5	1.4
Compacted moist soil	17	0.3	2.3
Clay	21.5	0.12	5.8

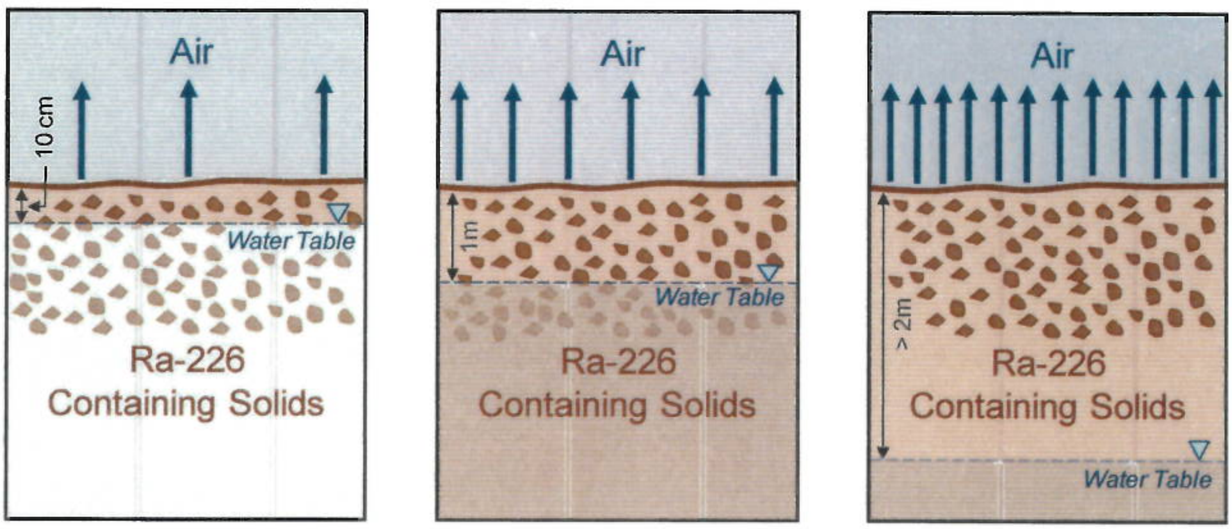
FIGURE 2-2 RADON PENETRATION OF VARIOUS COVERS (U.S. EPA 1982)



2.3 DEWATERING AND RADON FLUX

The relationship between the thickness of dry tailings and radon flux can be explained based on Figure 2-3. As the water in pores is replaced with air, more radon becomes available for exchange with air as radon is better able to diffuse through the tailings to the air/tailings surface. When the pore space in the porous material is filled with water, the diffusion coefficient is about 1/100th of that in pores filled with air (e.g., Tanner 1964). Therefore, it is expected that as the tailings dewatering progresses, radon flux to air will also increase. However, as seen later in Section 5.2, due to the short half-life of radon (3.82 days), a tailings thickness greater than about 3-5 m is effectively equivalent to an infinitely thick radon source, because the radon generated below such thicknesses will decay before it can diffuse through to the surface of the tailings.

FIGURE 2-3 EFFECTS OF DEPTH TO WATER TABLE ON RADON FLUX



3.0 TAILINGS AND COVER CHARACTERISTICS

The following Section, which describes Cell 2 and the characteristics of available cover materials, is based on information in MWH (2011) as well as recent information collected by Tellco (2012).

3.1 TAILINGS

The Mill tailings are reported as generally silty sand but heterogeneous due to the placement process. Based on grain-size analyses performed on the tailings, sand-sized particles are dominant with the remainder being silt- and clay-sized particles. The average grain size distribution for the Mill's tailings, based on 13 samples, consists of 57% sand, 26% silt, and 7% clay.

The activity of radium-226 in the tailings is reported by MWH at 981 pCi/g. This value was used in this report as the average activity for all the calculations. However, there is some uncertainty about the radium-226 activity present in the tailings[1]. The effect of this uncertainty was analyzed assuming a 25% range in Ra-226 activity.

The tailings cells at the Mill were lined with a synthetic geomembrane liner which has led to the long-term accumulation of water from infiltration of precipitation and saturation of the tailings. During and for a period after placement, the tailings were submerged under impounded water. The submerged tailings were primarily comprised of smaller particle size material (slimes). The perimeter of the tailings cells comprised a mixture of particles (slimes and sand) which deposited on the perimeter beaches. The area was not covered with water but was wetted and kept saturated. During the pre-closure period, the beaches became unsaturated and a random fill cover was placed on the tailings. By 2008, the entire surface of Cell 2 had been covered with a random fill soil cover. Table 3-1 provides some key characteristics of the tailings as provided in MWH (2011).

[1] The average grade of ore processed at the Mill since its inception is estimated to be approximately 0.350% U_3O_8. Assuming secular equilibrium in the ore between uranium-238 and radium-226, and that all radium in the original ore goes into the tailings, the activity of radium-226 will be calculated as (0.00350 g U_3O_8/ g ore) x (0.848 g U-238/ g U_3O_8) x (33,000 pCi U-238/ g U-238) = 981 pCi U-238/g ore. Although EFRI estimates the average grade of ore processed at the Mill to be approximately 0.350% U_3O_8, the average grade of ore that generated the tailings deposited into the cells may have varied as between Cell 2 and Cell 3. As a result, although 981 pCi/g radium-226 is EFRI's best estimate, there is some uncertainty as to the average grade of radium-226 in Cell 2.

TABLE 3-1 TAILINGS CHARACTERISTICS

Parameter	Value
Thickness	30 ft. (914 cm)
Radium activity concentration	981 pCi/g
Radon emanation coefficient	0.19 (based on laboratory data)
Specific gravity	2.75 (based on laboratory tests)
Placed density	74.3 pcf (based on laboratory tests)
Porosity	0.57 (calculated)
Long-term moisture content	6% (conservative assumption based on NRC)

3.2 COVER

In 1996, TITAN designed a 'final' cover for protection of the tailings in the long-term. The TITAN cover comprised 3 ft. of random fill, one foot of clay, another 2 ft. of random fill and a rock cover (from bottom to top). By 2008, Cell 2 had been completely covered by a layer of random fill of varying depths. MWH (2011) has proposed an updated cover design which recommends three layers of random fill including 2.5 ft. un-compacted (minimally compacted to about 80% standard Proctor compaction), 2.5 ft. compacted (to 95%), and 3.5 ft. compacted (to 80%), and 0.5 ft. of a gravel-admixture for erosion protection. MWH's proposed updated cover design is currently under review by DRC.

The existing interim cover (and the one studied for the drying period) consists of the random fill stockpiled at the site. Table 3-2 provides characteristics of the random fill as provided in MWH (2011).

TABLE 3-2 CHARACTERISTICS OF RANDOM FILL

Parameter	Value
Radium activity concentration	0 (assumed based on guidance in NRC 1989)
Radon emanation coefficient	0.19 (based on laboratory data)
Specific gravity	2.67
Placed density	93.4 pcf (low compaction) and 110.9 pcf (high compaction)
Porosity	0.44 (low compaction) and 0.33 (high compaction)
Long-term moisture content	7.8% (laboratory results and NRC estimation method)

3.3 MEASUREMENTS OF THICKNESSES AND RADON FLUX

Past measurements of Cell 2 indicate that the average radon flux over the entire cell (including sections submerged in water, saturated beaches and under-cover areas) never exceeded the 20 pCi m^{-2} s^{-1} standard before 2012. The proposed updated final cover is also predicted to comply with the regulations (MWH 2011); however, recent measurements have shown an increase in radon flux as dewatering has progressed. The average of the most recent radon measurements on Cell 2 in 2012 exceeds the 20 pCi m^{-2} s^{-1} standard. Table 3-3 shows average radon flux measured on Cell 2 since 1992.

During 2013, cover depth and the 'thickness of exposed sand' (i.e. dry tailings) and 'feet of solution' (i.e. wet tailings) were measured in test pits at 10 of these same locations on Cell 2. Figure 3-1 provides a map of Cell 2 showing the locations of the 10 sampling locations and test pits. Table 3-4 shows the overall average of measured levels of radon flux at each of these 10 sampling locations. Both Figure 3-1 and Table 3-4 provide the thicknesses of wet and dry tailings, the thickness of the existing cover material and radon fluxes at each test pit location.

TABLE 3-3 AVERAGE RADON FLUX MEASURED ON CELL 2

Year	Beach	Under cover	Both
1992	12.9	7	9
1993	27.5	9.7	12.3
1994	23.3	7.7	10
1995	28.4	6.1	9.5
1996	36.2	14.2	17.3
1997	41.3	7.4	12.1
1998	41.9	9.8	14.3
1999	25.7	12.4	13.3
2000	23.5	7.9	9.3
2001	32.2	18.2	19.4
2002	62.8	15.1	19.3
2003	71.5	13.3	14.9
2004	73.7	12.6	13.9
2005	55.8	6.6	7.1
2006	65.7	7.9	8.5
2007	50.2	13.1	13.5
2008*	-	3.9	3.9
2009	-	13.7	13.7
2010	-	12.8	12.8
2011	-	18	18
2012**	-	25.9	25.9

unit: pCi m^{-2} s^{-1}.

* First year with no beaches exposed (all under interim cover).

** Represents the average of four measurement events taken in 2012.

FIGURE 3-1 2011 AND 2012 SAMPLING LOCATIONS AND 2013 THICKNESSES

Source: Google Earth; Cell 2 boundaries and sample locations based on Figure 2 in Tellco (2012).

TABLE 3-4 TAILINGS AND COVER THICKNESS AND RADON FLUX MEASURED IN LOCATIONS SAMPLED IN 2011 AND 2012

Sampling and Test Pit Location	Thickness, ft.			Radon Flux, pCi m^{-2} s^{-1}	
	Cover	Dry Tailings	Wet Tailings	September 2011	October 2012
D22	3.23	11.40	4.23	18.9	36.4
D25	1.17	14.71	4.16	23.8	40.8
D28	3.77	10.92	10.21	63.7	63.5
D30	5.67	10.13	11.92	48.2	57.5
D48	8.88	11.13	10.00	2.5	2.7
D85	5.77	12.98	13.82	6.8	6.8
D37	2.42	17.96	5.63	34.4	43.8
D44	4.96	13.21	11.41	89.6	90.3
D42	4.38	8.00	18.41	16.9	16.2
D77	3.29	6.96	20.05	69.9	67.7

Table 3-5 shows the change in average observed water levels in the slimes drain standpipe in Cell 2 and the average observed radon flux from the entire surface of Cell 2 since 2008. The third column of Table 3-5 shows the year-to-year difference in observed water level in the Cell 2 slimes drain standpipe. Column 4 shows the average Cell 2 radon flux from the entire surface of Cell 2 for each year, and column 5 shows the year-to-year change in average radon flux. (Values in brackets reflect year-to-year lowering in water levels or radon flux.)

One important observation is immediately apparent, namely that a lowering of the water level in Cell 2 results in an increase in the average radon flux and an increase in water level results in a decrease in the average radon flux. This observation from field data supports the previously noted observation based on theory.

TABLE 3-5 STANDPIPE WATER LEVEL AND RADON FLUX

Year	Water Level (fmsl)	Δ Water Level From Year to Year (ft) Values in brackets reflect decrease in water level	Flux per Year (pCi m^{-2} s^{-1})	Δ Flux From Year to Year (pCi m^{-2} s^{-1}) Values in brackets reflect decease in radon flux	Δ Flux / Δ Water Level Values in brackets reflect decreases
2008	5600.56		3.9		
		(0.397)		9.8	$\frac{9.8}{(0.397)}$ =24.7
2009	5600.163		13.7		
		0.256		(0.9)	$\frac{(0.9)}{0.256}$ =3.2
2010	5600.419		12.8		
		(1.005)		5.2	$\frac{5.2}{(1.005)}$ =5.2
2011	5599.414		18		
		(2.104)		7.9	$\frac{7.9}{(2.104)}$ =3.7
2012	5597.31		25.9		

Column 6 is the ratios of the year-to-year change in average radon flux levels divided by the corresponding year-to-year change in water levels, which, in effect, is a global derivative reflecting the slope of the underlying curve. Roughly speaking, based on those observations, the average radon flux increases by about 4 pCi m^{-2} s^{-1} (with a range of about 3 to 5 pCi m^{-2} s^{-1}). Although based on limited data, it is noteworthy that since 2008 the change in radon flux has been consistently inversely related to changes in water levels, and the changes have been relatively consistent over the last three years.

4.0 METHODOLOGY

The radon model used for calculations in this report is that described in the U.S. NRC Regulatory Guide 3.46 (1989) for Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers. This methodology was used to calculate radon flux from the bare tailings, and also to estimate the cover depth required to keep the radon flux below the limit of 20 pCi m^{-2} s^{-1} as more of the tailings become dry.

4.1 CALCULATION METHODOLOGY

The NRC model uses a one-dimensional steady-state gas diffusion model. Fundamental parameters used in this model include the thicknesses, densities, specific gravities, moisture contents, radium activities, radon diffusion coefficients, and radon emanation coefficients of the materials (tailings and cover).

Table 4-1 lists all the parameters and equations used by the NRC model, as well as parameter values specific to Cell 2 as provided in MWH (2011). With the parameters provided in Table 4-1, assuming a dry tailings thickness of 10 ft. and a cover thickness of 3 ft. with a low compaction (80%) random fill, a diffusion coefficient of about 0.03 cm^2/s can be estimated. For this scenario, a theoretical radon flux of about 241 pCi m^{-2} s^{-1} would be estimated, which is higher than the actual measured radon flux in Cell 2. In order to refine the assumptions used in the model, the model was adjusted to take into account the results of the test pit field work referred to in Section 3.3 above, as discussed in Section 4.2 below.

4.2 ANALYSIS OF TEST PIT DATA

Radon flux values estimated using the parameter values provided in Table 4-1 appear, sometimes, to be several times higher than those estimated from recent test pit data referred to in Section 3.3 above. Therefore, an average soil diffusion coefficient (Dc) was back-calculated for the average cover thickness and average dry tailings thickness (4.35 ft. and 11.74 ft., respectively) at 0.0086 cm^2/s using all 2011/2012 samples. Using the average Dc for individual sampling points generally produces fluxes consistent with those measured, except for sample D25, where a thick dry tailings and little cover has actually resulted in a flux lower than expected. This could be the result of a local variation in the characteristics of the soil cover, e.g. degree of compaction or moisture content. The average Dc was modified by removing sample D25 from the averaging and a modified average Dc of 0.0098 cm^2/s was back-calculated. Figure 4-1 compares the estimated radon flux (based on the modified average Dc) to the measured fluxes, which shows a reasonable correlation.

Although further adjustments are possible, given the overall uncertainty, a nominal diffusion coefficient of 0.01 cm^2/s would seem reasonable, based on the test pit data. This diffusion coefficient is lower than previously estimated (at 0.03 cm^2/s in Section 4.1) for unconsolidated random fill cover and thus provides a more effective radon barrier than previously considered.

TABLE 4-1 PARAMETER VALUES AND EQUATIONS

Description	Parameter	Unit	Selected Value	Comment	Equation no.
Specific activity of radium-226 in tailings	R_t	pCi/g	981	Section 2.1	-
Dry bulk mass density of tailings	ρ_t	g/cm^3	1.19	MWH 2011	-
Radon emanation coefficient for the tailings	E_t	-	0.19	MWH 2011	-
Radon decay constant	λ	s^{-1}	2.10 x 10^{-6}	NRC 1989	-
Specific gravity of tailings	G_t	-	2.75	MWH 2011	-
Mass density of water	ρ_w	g/cm^3	1	NRC1989	-
Long-term average moisture content of tailings after dewatering	W_t	dry wt. percent	6	NRC 1989; MWH 2011	-
Porosity of tailings	n_t	-	0.57	MWH 2011	-
Moisture saturation fraction of tailings	m_t	-	0.125	-	Equation 8
Diffusion coefficient for radon in the total pore space of the tailings	D_t	cm^2/s	0.0499	-	Equation 7
Thickness of tailings	xt	cm	305	10 ft	-
Radon flux from bare tailings source	J_t	pCi m^{-2} s^{-1}	691	-	Equation 9
Dry bulk mass density of soil cover	ρ_c	g/cm^3	1.50	MWH 2011, 80%	-
Specific gravity of soil cover	G_c	-	2.67	MWH 2011	-
Long-term average moisture content of soil cover	W_c	dry wt. percent	7.8	MWH 2011	-
Porosity of cover soil	n_c	-	0.44	-	Equation 4
Moisture saturation fraction of cover soil	m_c	-	0.265	-	Equation 8
Diffusion coefficient for radon in the total pore space of the tailings	D_c	cm^2/s	0.030 *	-	Equation 7
Equilibrium distribution coefficient for radon in water and air	k	pCi/cm^3 water per pCi/cm^3 air	0.26	NRC1989	-
Inverse relaxation length for cover soil	b_c	cm^{-1}	0.0084	-	Equation 10
Thickness of soil cover	X_c	cm	91	3 ft soil (80% compaction for sample calculation referred to in Section 4.1)	-
Interface constant for tailings	a_t	cm^2/s	0.013	-	Equation 11
Interface constant for cover soil	a_c	cm^2/s	0.0037	-	Equation 11
Inverse relaxation length for tailings	b_t	cm^{-1}	0.0065	-	Equation 10
Radon flux from cover	J_c	pCi m^{-2} s^{-1}	241	-	Equation 12

Equations based on NRC (1989):

Equation 4: $n_c=1-\rho_c/G_c.\rho_w$

Equation 7: $D=0.07\exp[-4(m-m.n^2+m^5)]$

Equation 8: $m_c=0.01\,\rho_c.W_c/n_c.\rho_w$; $m_t=0.01\,\rho_t.W_t/n_t.\rho_w$

Equation 9: $J_t=10^4\,R_t.\rho_t.E_t\sqrt{(\lambda.D_t)}.\tanh(X_t\sqrt{(\lambda/D_t)})$

Equation 10: $b_c=\sqrt{\lambda/D_c}$; $b_t=\sqrt{\lambda/D_t}$

Equation 11: $a_c=n_c^2.D_c[1-(1-k)m_c]^2$; $a_t=n_t^2.D_t[1-(1-k)m_t]^2$

Equation 12: $J_c=(2J_t.\exp(-b_c.X_c))/(1+(\sqrt{(a_t/a_c)}.\tanh(b_t.X_t))+(1-(\sqrt{(a_t/a_c)}.\tanh(b_t.X_t)).\exp(-2b_c.X_c))$

* Modified later (Section 4.2)

FIGURE 4-1 ESTIMATED RADON FLUX BASED ON THE RECOMMENDED AVERAGE DIFFUSION COEFFICIENT (0.01CM²/S) COMPARED TO MEASURED FLUXES

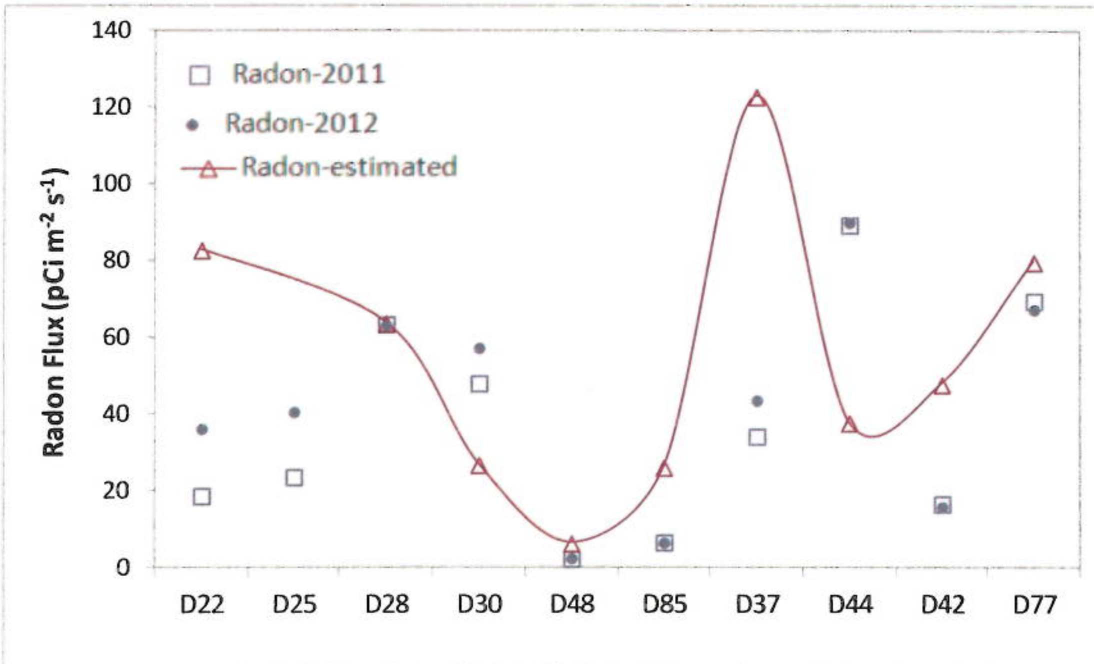


Table 4-2 compares the U.S.EPA's HVLs with the ones estimated for the two soil covers characterized by MWH (2011), and the one with an average Dc of 0.01 cm^2/s, which shows that the actual interim cover with an average Dc of 0.01 cm^2/s is performing with an attenuation coefficient between that for the MWH 80% and 95% compaction and greater than the attenuation coefficient for EPA's compacted moist soil.

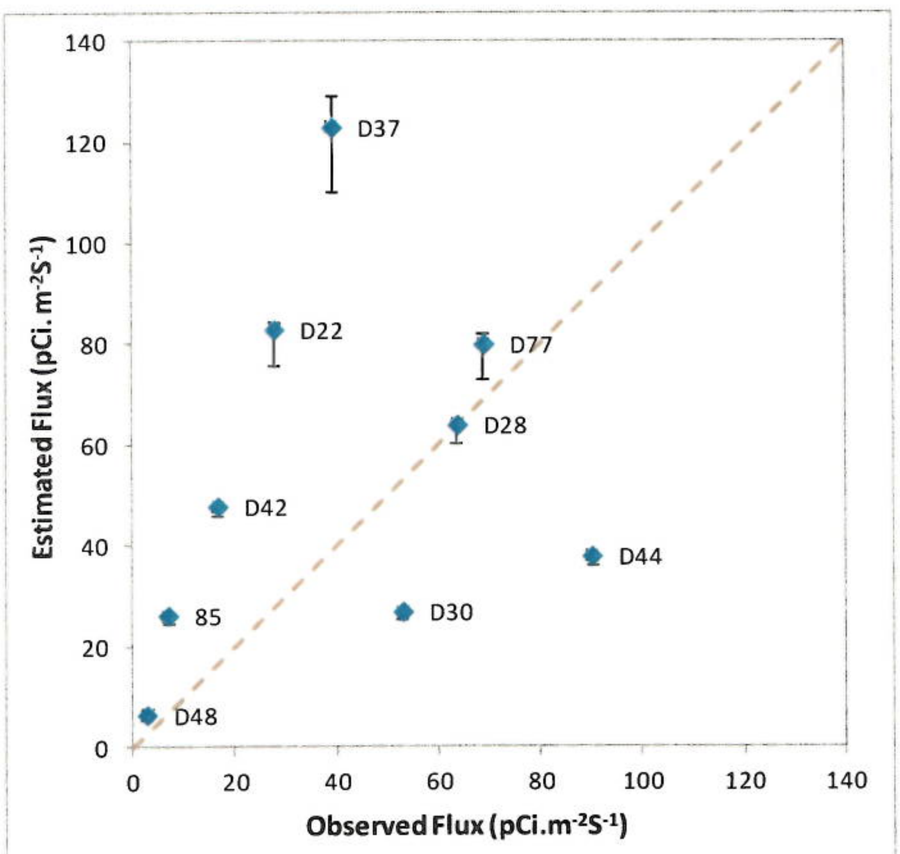
TABLE 4-2 RADON ATTENUATION OF VARIOUS COVERS

Cover	Moisture (%)	HVL (meters (m))	Attenuation coefficient (1/m)
U.S. EPA 1986			
Sandy soil	3.4	1	0.7
Soil	7.5	0.75	0.9
Soil	12.6	0.5	1.4
Compacted moist soil	17	0.3	2.3
Clay	21.5	0.12	5.8
Estimated from Cell 2 Data			
80% compaction (MWH)	7.8	0.55	1.55
95% compaction (MWH)	7.8	0.21	3.27
Average Dc (0.01cm^2/s)	-	0.43	2.47

4.3 RADIUM-226 ACTIVITY IN TAILINGS

As discussed in Section 3.1, there is some uncertainty about the radium-226 activity present in the tailings. A sensitivity analysis was therefore completed assuming ± 25% variation in the average activity proposed by MWH (2011) of 981 pCi/g. Average Dc's were back-calculated for these two activities (736 and 1226 pCi/g) and were applied to individual sample locations. The back-calculated Dc's were 0.012 and 0.0084 cm^2/s for the lower and higher activities, respectively. Estimated and observed radon fluxes for the three radium-226 activities (and their corresponding Dc's) are shown on Figure 4-2. It is noted from this figure in general the radon flux (out of soil) is not very sensitive to radium-226 activity in tailings and, moreover, does not materially reduce the scatter in the data which most likely arises from a simplification of the actual physical conditions in Cell 2.

FIGURE 4-2 SENSITIVITY OF ESTIMATED RADON FLUX TO RADIUM-226 ACTIVITY IN TAILINGS



Note: the points show fluxes estimated for an average radium-226 activity (981 pCi/g), while the bars represent the range of fluxes calculated using ± 25% variation in the average activity.
The dashed line represents a perfect correlation between estimated and observed fluxes.

5.0 RESULTS AND CONCLUSIONS

5.1 TAILINGS DEWATERING AND RADON FLUX

Based on test pit data, the nominal average thickness of the random fill cover is approximately 4.35 feet. Figure 5-1 shows the theoretical effect of increasing depths of dry tailings up to a maximum depth of 30 feet to account for the dewatering process. It is evident from the figure that with the current depth to water table (thickness of dry tails) of about 11.74 ft., the anticipated radon flux is nearly at its theoretical maximum. The corresponding theoretical radon flux for the assumed conditions is about 40 pCi m^{-2} s^{-1}, slightly conservative compared to the 2012 measured average of 25.9 pCi m^{-2} s^{-1}. However, given the available data, the theoretical radon flux of 40 pCi m^{-2} s^{-1} is considered to be a fairly close approximation to the actual measured radon flux.

FIGURE 5-1 ESTIMATED AVERAGE RADON FLUX FROM BARE AND COVERED TAILINGS

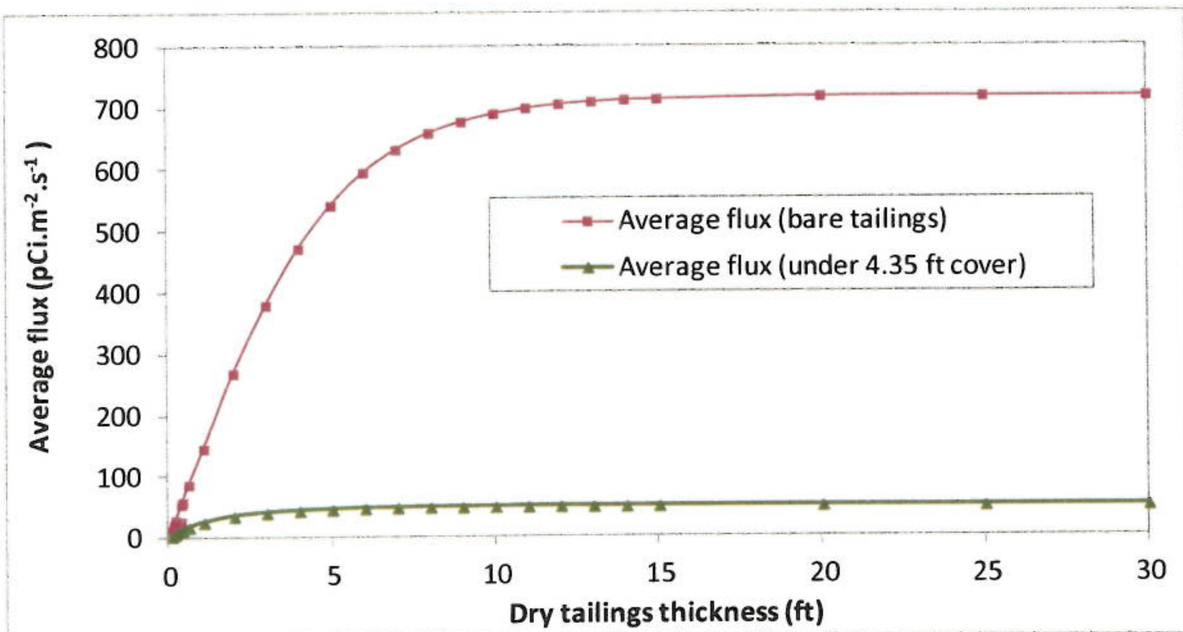
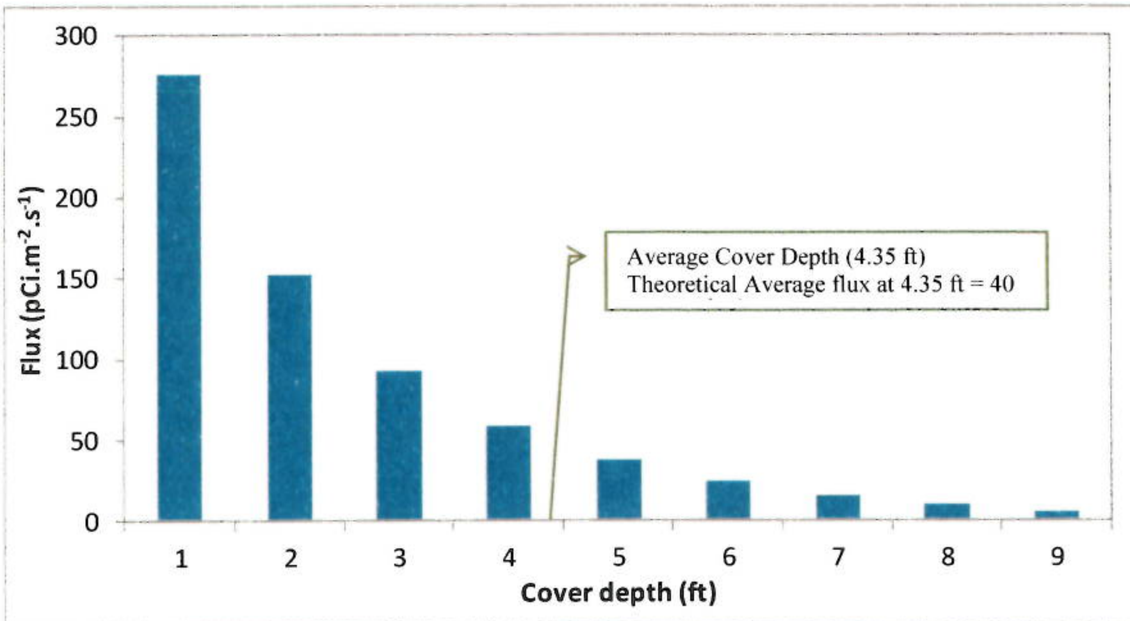


Figure 5-2 shows the theoretical estimated flux from the current dry tailings for different cover thicknesses. With 4 to 5 ft. of cover (average current thickness), the estimated flux is about 40 pCi m^{-2} s^{-1}. Again, this theoretical estimated flux is considered conservative and, based on the fact that current average flux at approximately 4.35 feet of cover is 26 pCi m^{-2} s^{-1}, not 40 pCi m^{-2} s^{-1}, appears to conservatively overstate the actual radon flux at each cover thickness. It should be noted that the average estimated flux assumes average conditions exist across the full Cell 2; however, as illustrated by Figure 5-2 there is some variability and as can be inferred from the figure, only a small change in average cover thickness would be needed to result in the observed average flux from 2012 of 26 pCi m^{-2} s^{-1}.

FIGURE 5-2 ESTIMATED FLUX VERSUS COVER DEPTH FOR THE CURRENT DRY TAILINGS*



* An average dry tailing thickness of 11.74 ft.

5.2 REQUIRED COVER THICKNESS

As suggested earlier, the radon flux from the bare surface of the tailings will continue to increase to some maximum value limited by the balance between increased radon potential and radon decay as dewatering continues with progressive lowering of the water table within the tailings. However, it can also be inferred from Figure 5-1 and the test pit data, which suggests average dry tailings of approximately 11.74 ft., that the rate of increase in radon flux from the surface of the cover with decreased water level (i.e., increased dry tailings thickness) is decreasing. This also suggests that the cover thickness is approaching its theoretical limit.

In 2012, the average flux was measured at about 26 pCi m^{-2} s^{-1}. The theoretical model conservatively predicts the radon flux under current conditions to be 40 pCi m^{-2} s^{-1}.

As previously noted, the current cover thickness varies between 2.4 and 9 feet in various locations, with an average of 4.35 ft. Based on the theoretical model, Table 5-1 shows the estimated cover thickness required to maintain the surface flux at or below 20 pCi m^{-2} s^{-1} as the thickness of the dry tailings increases.

The estimated cover thicknesses in Table 5-1 are based on the theoretical model, which predicts that a cover thickness of 5.79 feet would be required to achieve a radon flux of 26 pCi m^{-2} s^{-1}, when in reality the current average cover of 4.35 ft. appears to result in that radon flux rate. Table 5-1 can therefore be considered to set a theoretical upper bound, based on the data available, and estimates that a total average thickness of 6.39 ft. would be sufficient to limit radon flux to 20 pCi m^{-2} s^{-1}, regardless of the depth of dry tailings. In fact, based on the Mill's actual experience and test pit results, a thickness of less than 6.39 feet may prove to be adequate to achieve that objective.

Data in Table 5-1 suggests that in order to achieve an overall radon flux of 20 pCi m^{-2} s^{-1}, irrespective of thickness of dry tailings, it would be necessary to add an average of about 2 feet of random fill increasing the cover depth to about 6.4

TABLE 5-1 ESTIMATED REQUIRED THICKNESS OF COVER

Dry Tailings Thickness, ft.	Average Flux from Bare Tailings, pCi m^{-2} s^{-1}	Average Flux under 4.35 ft. of Cover, pCi m^{-2} s^{-1}	Required Cover Thickness *, ft.	
			to achieve 20 pCi.$m^{-2}s^{-1}$	to achieve 26 pCi.$m^{-2}s^{-1}$
11	700	49.5	6.38	5.79
12	706	49.6	6.38	5.79
13	710	49.7	6.38	5.80
14	713	49.7	6.38	5.80
15	714	49.7	6.39	5.80
20	718	49.8	6.39	5.80
25	718	49.8	6.39	5.80
30	718	49.8	6.39	5.80

* Inclusive of existing cover

As discussed in Section 2.2, a simple method for estimating the required cover thickness is to use the half-value layer (HVL) which is the thickness of material that reduces radon emissions to one-half of its initial value. For a nominal average an average diffusion coefficient of 0.01 cm^2/s, the HVL can be estimated at 0.43 m (1.4 ft.). The HVL can be used to calculate the impact of any depth of soil cover on radon reduction. For example in order to reduce the current average radon flux of 20 pCi m^{-2} s^{-1} (average measured in 2012) to 20 pCi m^{-2} s^{-1}, a 30% reduction in flux is required (radon transmission or T=0.7). The soil thickness (t) to achieve this can then be calculated as $t= - HVL * \ln(T)/ 0.693 = -0.43* \ln(0.7)/0.693= 0.16$ m = 0.5 ft. Thus, an additional 0.5 ft. of random fill cover (at between 80% and 95% compaction) would be expected to reduce the average radon flux from the cover of Cell 2 to below 20 pCi m^{-2} s^{-1}.

If the rate of increase of radon flux per foot decrease in water level of 3 to 5 pCi m^{-2} s^{-1}observed between 2009 and 2012 is representative, noting that any such rate is expected to decrease as dewatering continues, and dewatering has been progressing at the rate of approximately one to two feet per year, it would be reasonable to expect that radon flux will increase by about 3 to 10 pCi m^{-2} s^{-1} over the next year as a result of dewatering. Adding this expected increment to the existing flux rate of 26 pCi m^{-2} s^{-1} would result in an expected flux rate of 30 to 36 pCi m^{-2} s^{-1}. Applying the foregoing formula, approximately 1.0 ft. of random fill (at between 80 and 95%

compaction), over the existing cover would be expected to reduce the average radon flux from the cover of Cell 2 to below 20 pCi m^{-2} s^{-1}.

Further, as previously noted, the current cover thickness varies between 2.4 and 9 feet in various locations, with an average of 4.35 ft. In order to achieve an overall radon flux of 20 pCi m^{-2} s^{-1}, and assuming parameters and conditions as outlined above, an average of an additional (about) 2 feet of random fill (at between 80 and 95% compaction) cover would reasonably be expected to be sufficient to reduce the surface radon flux to below 20 pCi m^{-2} s^{-1}, regardless of the depth of dewatered tails.

The dewatering operation is expected to take several years to complete and if addition of random fill is not practicable, exceeding the radon flux standard will be an unavoidable but temporary consequence of the dewatering actions required to reclaim Cell 2.

6.0 REFERENCES

MWH Americas Inc. 2011. Pages from the Updated Tailings Cover Design Report.

Tanner, A.B. 1964. *Radon Migration in the Ground: A Review".* In the Natural Radiation Environment, pp161-190, J Adams and W. Lowder. Eds, University of Chicago Press.

Tellco Environmental 2012. *National Emission Standards for Hazardous Air Pollutants 2012 Radon Flux Measurement Program White Mesa Mill.*

TITAN Environmental 1996. Pages from the Tailings Cover Design report.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000. Sources and Effects of Ionizing Radiation – Volume 1: Sources. Report to the General Assembly, with Scientific Annexes, United Nations, New York.

United States Environmental Protection Agency (U.S. EPA) 1982. *Final Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192) - Volume I.* EPA 520/4/82/013-1, October.

United States Environmental Protection Agency (U.S. EPA) 1986. Background information document. *Standard for Radon-222 Emissions from Licensed Uranium Mill Tailings.* EPA/520/1-86-009.

United States Environmental Protection Agency (U.S. EPA) 1998. Regulations as found in 40 CFR 61 Subpart W National emission standards for radon emissions from operating mill tailings. April.

United States Nuclear Regulatory Commission (NRC) 1989. Regulatory Guide 3.64 Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers. June.